# HIGH PERFORMANCE AERONAUTICAL PAVEMENTS

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The Port Authority of New York & New Jersey manages and maintains the three major airports in the New York City metro area, LaGuardia, Newark International and John F. Kennedy International. Due to the high volume and heavy aircraft loadings on these pavements, Portland cement concrete has been the material of choice when the construction schedule permits. Obtaining a flexural strength of 700 or 750 psi within the FAA P-501 specification was never a problem, but there was more shrinkage cracking, curling, and spalling than desirable. Therefore, modifying our specifications to increase concrete durability and reducing shrinkage cracking was a top priority to reduce maintenance costs and extend the service life of our pavements while at the same time obtaining the desired flexural strength.

To reduce shrinkage cracking, curling and increase durability, it was decided the best approach would be to increase the size and quantity of coarse aggregate in the mix, while keeping the total water as low as possible, without using excessive amounts of High Range Water Reducers (HRWR). The Port Authority mixes evolved from specifying a maximum top size aggregate of 1.5-inch to 2-inches to 2.5-inches. However, as the stone size and quantity of coarse aggregate increased, it became apparent that a uniform combined aggregate gradation was necessary to eliminate segregation. Equally important, it was necessary to develop mix designs with low water demand and with the desired workability. It was also important to develop control and test procedures to assure ourselves that the amount of water in the concrete mixes being delivered did not exceed the design mix water content.

Our high volume stone mixes with a W/C at about 0.4 were tested for freeze-thaw durability, shrinkage potential and permeability. These mixes were tested for freeze-thaw durability in accordance with ASTM C-666. Mixes with an air content as low as 3% had a weight loss of only .8% and a Relative Dynamic Modulus of 85% at 700 cycles. The shrinkage potential of these mixes when tested in accordance with ASTM C-157 at 28 days was below .04%. Permeability of this concrete when tested by the Coulomb Test, AASHTO T-277, produced values in the range of 1000 – 2000, which is indicative of low permeability concrete. These outstanding properties emphasize the importance of designing mixes with low total water and paste contents for durable concrete. Mixes with a large maximum stone size and high volumes of coarse aggregates can be placed at a low W/C ratio. However, acceptance testing of the concrete should include the field microwave test, AASHTO TP-23, to confirm that the water in the mix is in fact at the design value.

The Port Authority had extended Runway 4L-22R at Newark International Airport by about 2,800 feet. This equates to approximately 120,000 cubic yards of concrete with a surface area of approximately 2 million square feet. Due to the large quantity of concrete required for this project, we decided that it would be an appropriate time to specify a concrete mix with a larger coarse aggregate, 2.5-inch maximum stone, and a uniform combined aggregate gradation. Basically we adopted the uniform aggregate gradation requirements given in ACI-302, which are given below:

- 0 – 4% retained on the top size sieve, 2.5-inches
- 8 – 18% retained on sieves below the top size and above the No. 100 sieve
- 1.5 – 5% retained on the No.100 sieve.

This specification for aggregate size and gradation was never attempted in the New York City metro area. We discussed our specifications with the aggregate and concrete suppliers and they agreed to supply the large and special blend of aggregates. Again, the purpose of specifying a larger coarse aggregate with a uniform gradation is to minimize paste content in the concrete mix thereby reducing drying shrinkage cracking and curling potential. We found that the conventional 2.5-inch aggregate, No. 357 stone, would not meet these requirements. We had a test pour with a conventional No. 357 stone and it segregated. In fact, the conventional No. 467 stone mixes also exhibited segregation. It took a blend of local No. 8, No. 57 and No. 3 size stones to achieve a uniform aggregate gradation. The blend is given in Table 1 below.

Table 1
Aggregate Blend –Runway EWR 4L-22R

| ASTM C-33 CONVENTIONAL AGGREGATES |
| --- |
| No. 3 Stone – 29% |
| No. 57 Stone – 18% |
| No. 8 Stone – 22% |
| Concrete Sand – 31% |

This blend of aggregate was first demonstrated in a test pour and produced a uniform and workable mix, with 70% aggregate by volume in the mix, that did not segregate. This blend of stone produced an aggregate production band that the contractor could work with and was acceptable to the Port Authority, even though it did not completely meet contract and ACI-302 gradation requirements. The bottom line was that we increased stone content in the mix and the mix was workable and did not segregate. The production gradation band is given in Table 2 below.

Table 2
Combined Aggregate Gradation – Runway EWR 4L-22R

| Sieve Size | Percent Passing |
| --- | --- |
| 2.5 inch | 100 – 94 |
| 1.5 inch | 76 – 88 |
| .75 inch | 77 – 65 |
| No. 4 | 39 – 27 |
| No. 30 | 21 – 15 |
| No. 100 | 5 – 1.5 |

Furthermore, upper limits where set for water in the mix and the entrained air had to be within the specified range. The specification required a mix design be submitted that meets the durability requirements given below:

- W/C Ratio $\leq$.4
- % Air – 3.5 –5.5%

To get the message out that we “mean it” with regard to controlling water and entrained air contents in concrete placed, (in addition to flexural strength requirements), no bonus payments would be made in accordance with P-501, if more than 20% of the concrete in a lot had a W/C ratio greater than 0.45 or 30% of the concrete in a lot had an air content less than 3.5%. A good specification and concrete mix design is worthless without a Quality Assurance testing program that ensures that the incorporated properties are being met. The water in the plastic concrete mix being placed was tested for each sublot in accordance with AASHTO TP-23 on the plastic concrete on-site, and the air in the mix was tested on-site for each sublot of concrete delivered in accordance with ASTM C-231. Both test results were statistically analyzed and a PWL was determined for W/C ratio and entrained air for each lot of concrete. Furthermore, bonuses would not be paid for a lot of concrete that exhibited plastic or drying shrinkage cracks.

The runway was extended from both south and north ends, and work was awarded approximately one year apart, under two separate contracts. The south end was awarded first, and work was completed in 1998. The pavement section is 20 to 24-inches in depth. For the southerly extension, the contractor decided to erect a central mix plant on-site, and slip-form the pavement. The mix design used is given in Table 3 below:

Table 3
Concrete Mix Design – EWR Runway 4L-22R

| | |
|---|---|
| Cement | 500 lbs |
| Granulated Blast Furnace Slag (GBFS) | 100 lbs |
| Fine Aggregate | 1,000 lbs |
| Coarse Aggregate | 2,220 lbs. |
| Water | 237 lbs. |
| Slump | 1.5 inches |
| Air Content | 4.5 % |
| Water Reducer | 15 oz. |
| Air Entraining | 20 oz.± |

Note the low slump required to slip-form the pavement. This mix required a high quantity of air entraining agent, 20 oz. per cu. yd., to get the air content to about 4% and additional effort was required to finish the surface of the pavement. The surface had a harsh open texture due to the low water content and high coarse aggregate content in the mix.

The concrete work on the south end was done for the most part, during the summer of 1998. On many days, concrete was placed when the ambient temperatures were at 90°F during placement. An evaporation retarder was sprayed on the concrete immediately behind the screed. A double application of a curing membrane was used to cure the concrete. To control cracking, it is essential that control joints be cut as soon as possible, usually within five hours of paving the concrete. The membrane was applied as soon as the concrete was finished. Control joints were cut on a 25-ft. pattern as soon as the concrete could support the saw, without marring the concrete. The test results for concrete placed on the south end of Runway 4L-22R are given in Table 4 below.

Table 4
Field Test Results – EWR-Southern 4L-22R

| | Average | Standard Deviation |
|---|---|---|
| Compressive Strength (28 days) | 5990 psi | 510 psi |
| Flexural Strength (28 days) | 916 psi | 85 psi |
| Slump (inches) | 1.25 | .60 |
| W/C (microwave) | .42 | .04 |
| Air % | 4.2 | .80 |
| No. of Tests | 279 | |

As can be seen, even with a relatively low cementitious factor of 600 lbs. when the water, aggregate gradation and air were controlled, obtaining the specified flexural strength of 700 psi was not a problem. In fact, the flexural strength average of 916 psi is well above the 700 psi specified. The compressive strength obtained was nearly 6000 psi.

The contract for the north end of the runway was awarded in 1998, but work was done in 1999. Here the contractor used essentially the same mix design as on the south end with the same blend of aggregates from the same sources. However, the concrete was supplied from a local batch plant, and conventional forming and concrete placement methods were used. The contractor used approximately 43 oz. per cubic yard of a High Range Water Reducer (HRWR) to obtain workability and maintain a W/C ratio of 0.40, for the mix design. Again, the specification required that 80% of a lot of concrete delivered to the site must have a W/C below 0.45 and 70% of the entrained air must be above 3.5% to receive a bonus payment. These are additional requirements to flexural strength that is specified in P-501, to obtain a bonus. It is our opinion that flexural strength alone does not provide a basis for giving bonuses, because alone it is not a good indicator of durable pavements. Our experience is that most of our infrastructure concrete is being replaced or repaired because it is not durable - - not because of insufficient strength.

With the use of a HRWR, the contractor was able to place the concrete at a 4 –5-inch slump. This allowed him to finish the concrete with considerable less labor and cost than the concrete that was slip-formed and placed at a 1.5-inch slump. Furthermore, getting the entrained air within the required range was much easier. The concrete was cured and control joints were installed the same as at the south end. The field test results are given in Table 5 below:

Table 5
Field Test Results – EWR North End 4L-22R

| | Average | Standard Deviation |
|---|---|---|
| Compressive Strength (28 days) | 6300 psi | 860 psi |
| Flexural Strength (28 days) | 870 psi | 98 psi |
| W/C (microwave) | .41 | .03 |
| Air (%) . | 5.1 | .86 |
| Slump (inch) | 4.0 | 1.1 |
| No. of test | 306 | |

There was more variability in the flexural strength received from the mix supplied from the off-site batch plant for the north end than with the concrete batched on site for the south end, as can be seen in the standard deviations for flexural strength results.

Both projects, to date, exhibit virtually no shrinkage cracking. The south end after being in service for three years has one 15-ft. drying shrinkage crack. Several slabs had cracks within several inches and parallel to the control joints. This would indicate these cracks were caused by the joint cutting operation. The north end shows the same regarding to shrinkage cracking. Only two slabs showed 10 – 15 ft. shrinkage cracks. Two slabs showed plastic shrinkage and two slabs showed cracks emanating from light cans.

During the past three years, most of our larger aeronautical concrete pavement projects were built to the aforementioned specification. One other project worth noting required extending several taxiways. It is worth noting because the total cement content was reduced and the coarse aggregate was increased more, the flexural and compressive strengths did not decrease. The mix design is given in Table 6 and test results are given in Table 7 below.

Table 6
Concrete Mix Design

EWR 154.218 Mix Design

| | |
|---|---|
| Cement | 430 lbs |
| GBFS | 140 lbs |
| Fine aggregate | 990 lbs |
| Coarse Aggregate | 2300 lbs |
| Water | 230 lbs |
| Slump | 4 – 5 inches |
| High Range Water Reducer | 57 oz |
| Air Content | 4.8 % |
| Air Entraining Agent | 2.5 oz |

Table 7
Field Test Results – EWR – 154.218

| | Average | Standard Deviation |
|---|---|---|
| Flexural Strength (28 Days) | 926 (psi) | 95 (psi) |
| Compressive Strength (28 Days) | 7770 (psi) | 980 (psi) |
| Slump (inches) | 5 | 1.5 |
| W/C (microwave) | .43 | .03 |
| Air % | 5.4 % | 1.55 |

The exceptional results produced by these mixes as shown by the test results and more importantly by the performance of this concrete must be attributed to a great extent to the attention paid to aggregate gradation, water, and air in the delivered concrete.

We analyzed the combined aggregate gradations provided on these three projects using Coarseness and Workability Factors being used by Mr. J.M. Shiltsone and others in the concrete industry. We have found that these mixes produced a range in the factors as follows:

| | |
|---|---|
| Coarseness Factor | 65-70 |
| Workability Factor | 29-32 |

The published information on mixes with these coarseness and workability factors indicate that the mixes should be workable and not segregate. This is, in fact, how the mixes performed. Therefore, these three projects confirm that these factors can be used to qualify the workability of mix designs. ACI committee 211 is proposing that these factors be considered when designing mix designs.

This Portland cement concrete pavement to date exhibits less than about 5% of the drying shrinkage cracking we experienced in our other concrete pavement work. The lessons learned from these projects are as follows:

- A larger coarse aggregate, 2.5-inches top size stone, with a uniform combined aggregate gradation and a relatively large volume of aggregate in the mix, 70%, does contribute to producing a durable mix that is less susceptible to cracking and reduces the permeability of the concrete.

- The delivered concrete can and should be tested in accordance with AASHTO TP-23 to accurately determine water in the delivered concrete mix. This parameter should be tied to bonus payments to reinforce the importance of reducing water in a mix to increase durability.

- Neither flexural nor compressive strength alone are a good indicator of durable concrete. Therefore, bonus payments should be made only when other parameters such as W/C and % air are within specifications.

- To reduce shrinkage cracking, it is important that control joints are cut as soon as possible. Depth of cut is of secondary importance.

- The additional requirements for bonus payments, that 80% of the concrete in a lot must have a W/C $\leq$ .45 and 70% of the concrete must have an air content above 3.5%, were achieved. On the south end, 50% of the lots received a bonus and on the north end 62% of the lots received a bonus. This specification is reasonable and most of all necessary to obtain durable and long lasting concrete.

- More attention is paid to details by concrete suppliers and contractors when a meaningful Quality Acceptance program that verifies that the key properties such as aggregate gradation, water, and air are tested for at the job site and adjustments to payments are made based on the quality of the concrete supply.